HIGH HEELED GAIT ANALYSIS OF ANKLE JOINT FORCES USING FORCE PLATFORM

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BY

KUMAR PRABHU KALYAN

(Roll No. 110BM0634)

UNDER THE SUPERVISION OF

PROF. A. THIRUGNANAM

DEPARTMENT OF BIOTECHNOLOGY AND MEDICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

Rourkela, Odisha, 769 008, India

May 2014

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

CERTIFICATE

This is to certify that the thesis entitled **"HIGH HEELED GAIT ANALYSIS OF ANKLE JOINT FORCES USING FORCE PLATFORM"** submitted by **KUMAR PRABHU KALYAN (110BM0634)** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Biomedical Engineering at National Institute of Technology, Rourkela is an original work carried out by him under my supervision and guidance. The matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree.

Date:

Place: Rourkela

Dr. A. Thirugnanam

Assistant Professor

Biotechnology and Medical Engineering

National Institute of Technology Rourkela

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KUMAR PRABHU KALYAN (110BM0634)

Biotechnology and Medical Engineering

National Institute of Technology, Rourkela

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ABSTRACT

Given the massive variety of individuals wearing high-heeled shoes, understanding the gait biomechanics associated with their use could provide insight into clinically preventable system issues. This is particularly necessary in today's atmosphere of practice of medicine, medical price reduction, and heightened health awareness.

An intra-subject comparative study of walking with low-heeled shoes versus high-heeled shoes and barefoot vs high heeled shoes were performed to find and elucidate changes in lower-extremity joint mechanisms related to wearing high-heeled shoes throughout level ground walking. A control group of eight female volunteers with no walking disorders underwent quantitative measurement of mesial and frontal plane lower-extremity joint performance, together with angular motion, muscular moment, power and work. While walking in high-heeled shoes, a major reduction in mortise joint region striated muscle moment, power, and work occurred during the stance phase, whereas hyperbolic work was performed by the hip skeletal muscles throughout the transition from stance to swing.

It was established from the study that wearing high heeled shoes for a longer period of time leads to ankle pain, joint ache and hip related problems. Thus avoiding high heeled shoes to the maximum possible extent and use of wedged heels would reduce ankle related problems keeping the style quotient intact.

Keywords: High heels, Force Platform, Ground reaction forces, Power expenditure, Subtalar Joint Axis, Ankle Joint.

CHAPTER 1

INTRODUCTION

INTRODUCTION

During human locomotion balance is continuously challenged. Throughout the gait cycle the body is forced to create a bodily property alteration because of disturbances to the body. A failure to compensate posture changes properly via combined action of muscles and joint may result in falls. A key to boost the balance is by extending the soundness of the system [1]. The alteration in gait pattern can be observed in case of female participants wearing high-heeled shoes. They exhibit longer cadence period, the direction of moment reaction about the ankle joint gets easily disturbed during stair ascent and descent, and they rely heavily on supports during upright movement while in bus/train as their centre of gravity of body continuously changes leading to unstable stance. Any upsets in the body balance are continuously relayed to the brain which signals the proper muscles into action and stays the individual from falling. Thus, neuroscience and signal systems play a very important role in keeping the balance throughout locomotion [2].

There is an increased societal pressure among the fairer sex which has led to a phenomenal rise in the use of high heeled shoes. Surveys of shoe usage have shown that thirty seven to sixty nine percentage of women wear high-heeled shoes on a regular basis [3]. Fashion magazines all round the world promote high-heeled shoes for women. The long-term physical repercussions of wearing high-heeled shoes include permanent disfiguration of gait, distortion of metatarsophalangeal joint in the foot and chronic pain. From literature study, it's been documented that the high-heeled shoes have several negative biomechanical effects in any case, posture and gait kinematics. Various studies in biomechanics of gait have been conducted in the past revealed scrutiny of gait parameters versus different heights of the shoes.

Previous investigations have shown that high-heeled shoes align the foot in plantarflexion; modifying the relative orientation of the skeletal structures of the ankle, midtarsal, and metatarsophalangeal joints; and alter the insertion angles of the foot and gliding joint muscles [4]. The alteration in anatomical position of the foot results in practical changes that embrace a shift in ground reaction forces toward the medial plane, a reduction in foot rotary motion throughout midstance, and an increase within the vertical ground reaction force at heel strike. The abnormal foot loading documented by these studies underlies several of the painful foot disorders related to the employment of high-heeled shoes.

The impact of high-heeled shoes on joint kinematic and kinetic changes proximal to the articulatio talocruralis has not been studied extensively. Enhanced hip and knee flexion throughout stance happens as a bodily property adaptation to the plantarflexed foot position and as a potential counteractive mechanism for engrossing impact masses. Sadly, such mechanisms have conjointly been concerned as a possible supply of knee pain and degeneration. Investigations driven by considerations concerning the role of high-heeled shoes within the alteration of posture and therefore the development of low-back pain have explored the impact of heel height on counteractive and adaptive changes in the spine [5]. Contrary to the standard clinical assumption of enhanced body part spinal curvature, most studies have shown that practiced high heeled shoe wearers show no modification or a discount in body part spine extension. Inexperienced users tend to increase trunk spinal curvature likewise as girdle and limb rotation while walking.

CHAPTER 2

LITERATURE REVIEW

2. Literature Review

Prior to conducting the study on the control group, extensive literature perusal was done with focus on the following topics:

2.1 The Subtalar Joint

The subtalar joint could be a composite joint shaped by three separate plane articulations placed superiorly to the talus and inferiorly to the tarsi-fibulare. Together the three surfaces offer a triplanar movement round the single joint axis and one in every of the functional joints of the foot and articulatio talocruralis. Often rumored as one axis, a turbinate screw axis and a bundle of axes, the subtalar joint is to blame for many movements concerning the ankle, inversion and eversion within the transversal plane, area flexion and flexure within the mesial plane, and adduction and abduction within the frontal plane [6]. Subtalar inversion helps to create stability of the foot throughout single-limb stance. Subtalar eversion is a mechanism of shock absorption when the foot makes contact with a surface. Five muscles facilitate management inversion of the subtalar joint axis and cross the medial aspect of the joint: tibialis muscle, tibialis, skeletal muscle digitorum longus, flexor hallucis and soleus. Four muscles are responsible for eversion of the subtalar joint axis: extensor digitorum longus, skeletal muscle tertius, skeletal muscle longus and skeletal muscle brevis [7].

It is the motion at this joint that allows the foot to adapt to a wide range of surfaces. Additionally there is substantial variability within the orientation of this axis in traditional individuals, so the relative motions also will vary among traditional individuals. The subtalar joint axis includes a wide accepted range of deviation and inclination. The variation of deviation is 4^0 to 47^0 with a typical deviation of 11^0 and a mean deviation of 23^0. Subtalar inclination angle ranges from 20.5^0 to 68.5^0 with a typical deviation of 9^0 degrees and mean variance being 42^0 degrees [8].

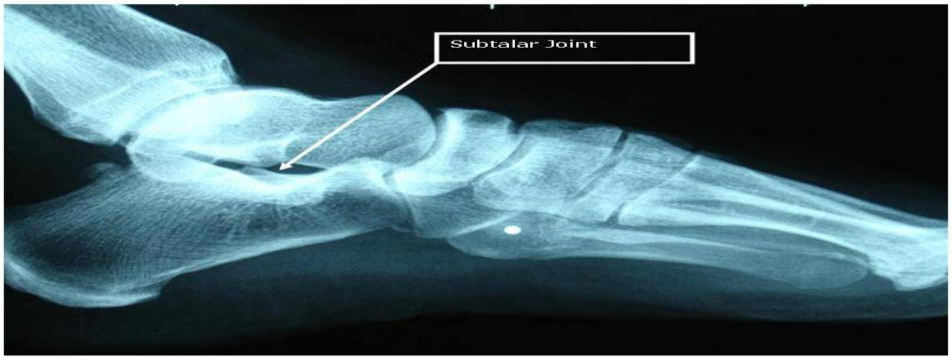

Fig 2.1 The Subtalar joint [1].

2.2 Ground Reaction Forces

Ground reaction force (GRF) is any external reaction force, specifically the one applied by the ground on the lower extremis. Ground reaction force is equal in magnitude and opposite in direction to the force that the body exerts on the supporting surface through the foot.

GRF values are often delineated by Newton's third law of motion, the action-reaction double. Several studies have viewed and accordingly accrued pressure beneath the foot with a rise in heel height in women wearing high-heeled shoes. But few studies have measured GRF values. In an exceedingly good study done, no significant variation in GRF values was found between younger and older participants or between experienced and inexperienced high heeled shoe wearers [9]. Another study measured vertical, anteroposterior and mediolateral direction of GRF values of gait in three completely different heel heights. The study showed a rise in vertical, anteroposterior and mediolateral ground reaction forces with accrued heel height. The maximum heel height of 7.62 cm showed a pronounced inflection compared to those of the lower heels and medium heels tested for vetrical GRF values [10]. Anteroposterior and mediolateral GRF appeared later within the stance and support phases for the upper heel height, however these did show a significant increase in GRF values.

In a study done it was found that the GRF increased linearly with speed of the walk. Thus speed of the walk shows a good intervention in the reaction forces and influences it [11].

2.3 Muscular Activity

In high heel gait and standing, several muscles situated within the lower extremities and the back are also worked, attributable to the area flexion of the foot. Muscles are at their peak for force generation once they are at resting length [12]. Once muscle length increases or decreases on the far side its resting length, muscle force production decreases as a bell shaped form. This relationship is seen in high heel wearers. When the heel is raised muscles fibers that innervate the muscles on the leg are shortened. The shortened muscles are currently inconsistent with its resting length-tension relation leading to less force production. The exaggerated area flexed position of the articulation talocruralis places the gastro-soleus muscle at a shortened and therefore less superior position on its muscle length-tension curve. Under such conditions, the area flexion system is at a less advantageous position for power and work generation and consequently, less propulsive talents.

2.4 The Motor Act

The gait cycle begins at the heel strike of the foot and ends at toe-off of the same foot. The normal gait cycle comprises four phases. When executed sequentially these provide the work output necessary to propel the body forward [13].

1) Heel strike: In this part only the heel comes in contact with the surface and the ankle is in a state of dorsiflexion. At this state the foot bears the whole body weight and needs a certain amount of force, mostly impact force, to facilitate forward movement.
2) Foot flat or mid stance: Prior to the heel strike, the ankle joint becomes neutral bearing the whole body weight on the foot, this stance is also known as the single support phase.
3) Heel off: In the next phase the heel moves up so does the ankle joint, on doing so there is a high impulse force that is applied on the forefoot, in this phase the ankle joint is plantar flexed.
4) Toe off: In this phase the toe lifts and the opposite leg in the swinging phase starts to lose momentum as it lands on the surface with a heel strike (opposite leg heel strike).

2.5 Previous Works

Moments concerning the subtalar joint axis were considerably different between the shoe conditions: high-heels versus flat shoes, and between high-heels versus barefoot. High-heel shoes generally depict a small positive inverting moment, however there was a bigger movement moment in case of the barefoot and flat walking conditions. All variations in electromyograph activity for the tibialis muscle, peroneals, lateral skeletal muscle and medial skeletal muscle were insignificant, but with a trend toward additional activity within the high-heeled condition for muscles that evert the heel (peroneals and lateral gastrocnemius) [14]. These muscles are compensating for the additional inverting moments of the bottom reaction forces while sporting high-heeled shoes.

The findings of the study indicate that the employment of high-heeled shoes alters designated proximal lower-extremity joint kinetic operate. These changes represent adaptive methods that maintain limb stability as the articulatio plana is forced into associate exaggerated plantarflexed posture and substitute for reduced area flexor operation in limb advancement through the re-doubled use of hip skeletal muscle activity. The changes, however modest might contribute to the creation of abnormal and doubtless injurious forces that will give rise to underlying problems in a number of proximal joints and spine pain complaints of habitual high-heeled shoe users [15]. The potential role of foot posture within the development of musculoskeletal disorders must be thought about when evaluating pain complaints or prescribing shoes, insoles, lifts and surgical treatments.

Previous studies are evidence that the high-heeled shoes caused bodily property changes, a loss of foot operate, and deformities of foot. But the body part spinal curvature in gait isn't measured. This study was conducted to check mechanics and interactions between high-heeled and high-forefoot gait by skin markers, and to seek out the influence of heel height to body part alignment. Vicon 370 three-dimension Gait Analysis System was used. Within the study, the lower extremity biomechanics in high-heeled and high-forefoot shoes were examined in twenty Korean female subjects. Results showed that the double support section multiplied in high-forefoot gait in linear parameters. In mesial plane mechanics, the body part spinal curvature slightly multiplied in high-forefoot gait, however that failed to increase in high-heeled gait. The knee flexion and articulatio plana plantarflexion multiplied in high-heeled gait, however articulatio plana pantar flexion reduced in high-forefoot gait. Clinically the amendment of articulatio plana motion wasn't considerably influenced to the body part spinal curvature [16]. However, high-heeled shoe users with low back pain are in all probability influenced by the magnification of paraspinal muscles and ligments.

Analysts have done some really innovative controls of X-ray beam pictures of the hip joints in resulting in these present circumstances view. These 'Fourier changes', as they are called, can give an exceedingly correct two-dimensional picture of the three-dimensional structure inside bones. At the point when connected to X-beam pictures of the hip joint, the scientists can focus the three dimensional course of action of what is known as the "cancellous" bone, the natural permeable honeycomb-like structure. The cancellous structures seem to take after the hypothetical lines of power accomplished by any joint, and anatomists have accepted that the structure of the bone co-develops with the changing drives on the hip, both in an ontogenetic sense (what the individual encounters in a lifetime) and a phylogenetic sense (how the species advances). The same courses of action drive bone statement (and the ingestion of calcium from the circulatory system) and the consequence is one's trademark inner bone structure, and additionally bone thickness, obviously imperative in osteoporosis.

CHAPTER 3

MATERIALS AND METHODS

3. Materials and Methods

3.1 Force Plate

The Force Plate is a metal platform with one or more sensors attached to give an electrical output proportional to the force applied on the plate. These electrical signals can also be interpreted to find out the other parameters such as the centre of pressure, velocity, moments, coefficient of friction, etc. At frequencies less than about 100Hz, the output of force plate is accurately proportional to the applied force and can be monitored using a display system through a data acquisition system (DAQ). Force plates are generally not used for measurements of impacts that last for less than few milliseconds. Mostly in force plates the sensors used are piezoelectric in nature. The piezoelectric material produces a charge distortion on application of force due to change in electron lattice structure.

The output voltage of a piezo element is given by

$$V = Q/C \tag{1}$$

, where C is the capacitance of the element, $Q = d_{33}F$ is the charge induced by the force applied in the direction perpendicular to the electrode surface.

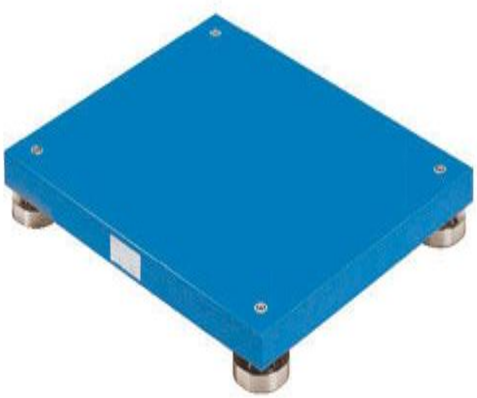

Fig 3.1 Force Plate by KISTLER™

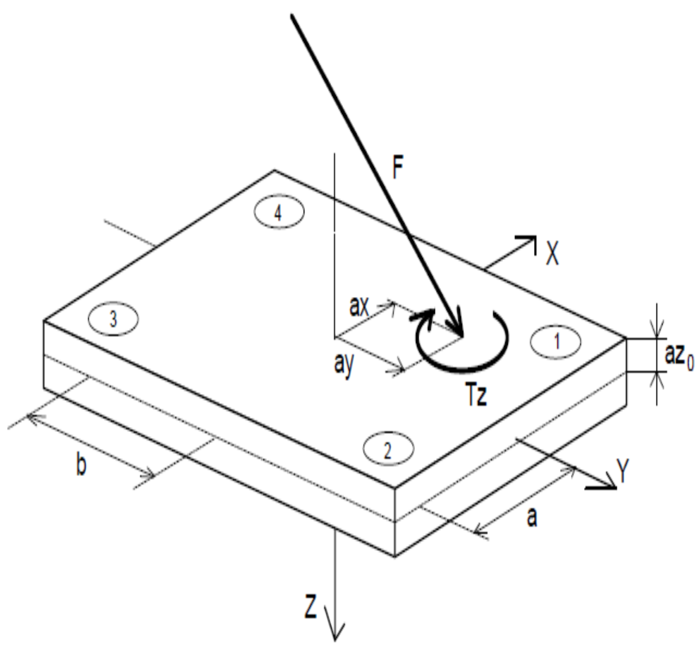

Fig 3.2 Various axes of the Force plate and components

3.2. Data Collection

Prior to the experiment ethical consent was obtained from the institute, and consent was also obtained from the volunteers. The data were collected from the force plate with the help of the data acquisition system. The volunteer was asked to walk at a self-selected walking speed (compelling her to walk at a predefined pace may lead to unnatural gait patterns). After 2-3 trials, the best natural gait pattern was recorded, she was made to walk on the force plate of 330 cms length for 20 secs in repeated cycles.

- The standard heels used in the experiment were labelled as follows :

1. High heels - 4.4 inches.
2. Flat heels - 1 cms.
3. Wedge Heels – 2 .1 inches.

3.3. Data Analysis

The data analysis was done from the ground reaction forces profile and the torque profile. The torque statistics were revealed by the processor, the force values and the power values were obtained from the processor. The governing equations which are the fundamentals in finding the results are:

3.3.1 Governing Equations:

Equation 1:

$$F_Z(t) = m \,.\, a_Z(t) \qquad (2)$$

where, $F_z(t)$ is the force acting along z axis at time t seconds,

$a_z(t)$ is the acceleration component along the z-axis at time t seconds, and

m is the mass of the volunteer.

Equation 2: Acceleration-time variation

$$a_z(t) = \frac{F_Z(t)}{m} - a_{oZ} \qquad (3)$$

where , $F_z(t)$ is the force acting along z axis at time t seconds,

$a_z(t)$ is the acceleration component along the z-axis at time t seconds,

m is the mass of the volunteer, and

a_{oz} is the static acceleration.

Equation 3: Velocity at a given time can be calculated by using the initial velocity and the acceleration obtained from the above equation

$$M_Z = b * (-f_x12 + f_x34) + a * (f_y14 - f_y23) \qquad (4)$$

where,M_Z = Moment of force along Z-axis.

f_x12 = force along x-axis measured by sensor 1 and 2.

f_x34 = force along x-axis measured by sensor 3and 4.

a and b are respective offsets.

Equation 4: Torque

$$T_Z = M_Z - F_Y * ax + F_X\, ay \qquad (5)$$

where, T_z is the vertical torque,and

F_x and F_y are the forces along x and y axes.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

The parameters in focus here are Ground Reaction Forces, Torque and Power Expenditure for volunteers under three conditions: with high heels, with flat sole shoes and in barefoot walking .

4.11 Volunteer 1

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<tr><th>Barefoot</th><th>High Heels</th></tr>
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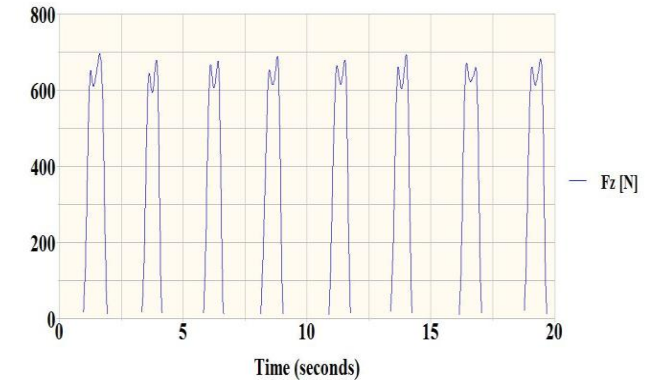
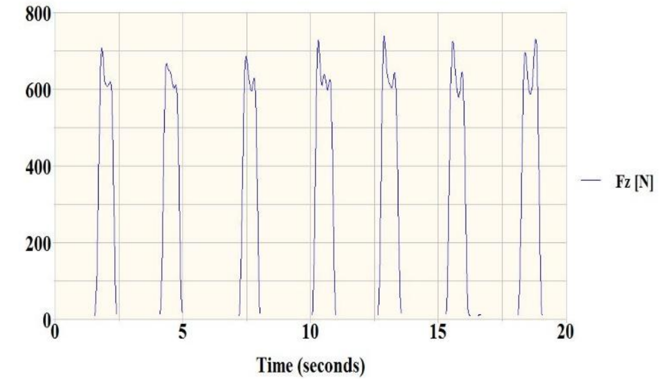
<tr><td>
</td><td>
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<tr><td>Fig 4.1 Ground Reaction Forces for Volunteer 1</td><td>Fig 4.4 Ground reaction forces for Volunteer 1</td></tr>
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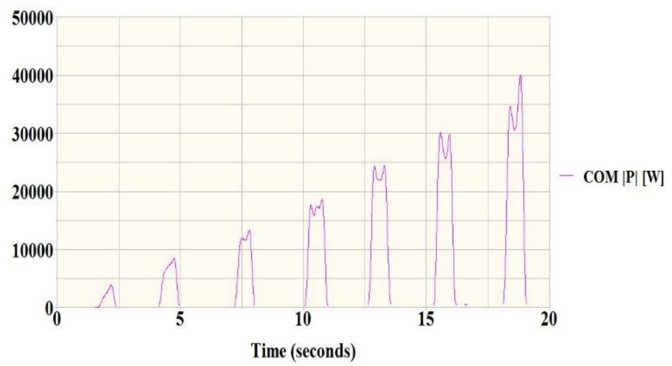
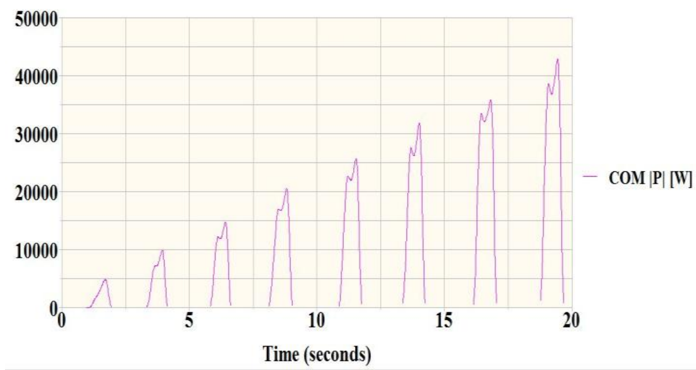
<tr><td>
</td><td>
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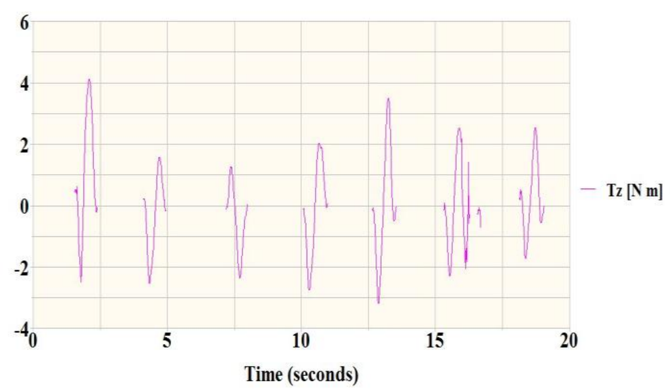
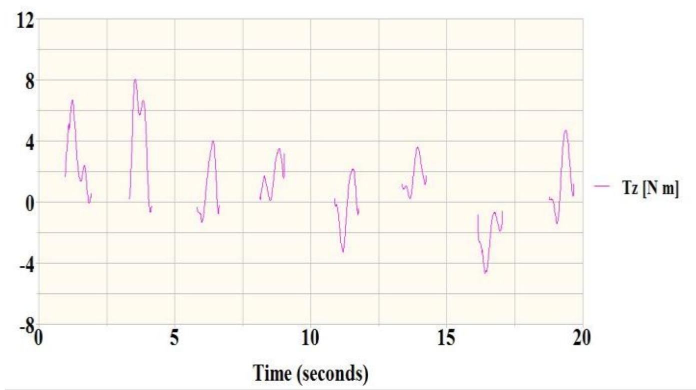
<tr><td>Fig 4.2 Power Expenditure for Volunteer 1</td><td>Fig 4.5 Power Expenditure for Volunteer 1</td></tr>
<tr><th colspan="2">Torque</th></tr>
<tr><td>
</td><td>
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<tr><td>Fig 4.3 Torque profile for Volunteer 1</td><td>Fig 4.6 Torque profile for Volunteer 1</td></tr>
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4.12 Volunteer 2

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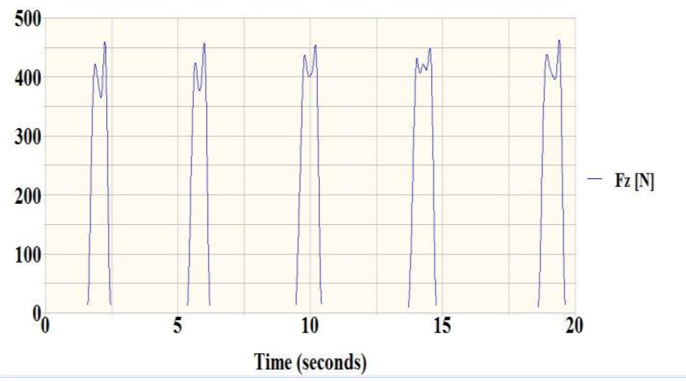
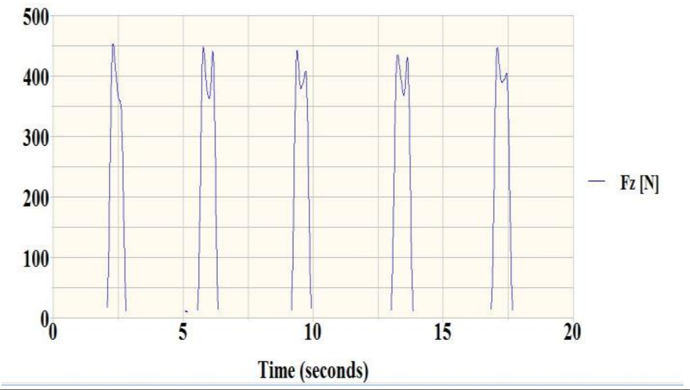
<tr><td>
</td><td>
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<tr><td>Fig 4.7 Ground reaction forces for Volunteer 2</td><td>Fig 4.10 Ground Reaction Forces for Volunteer 2</td></tr>
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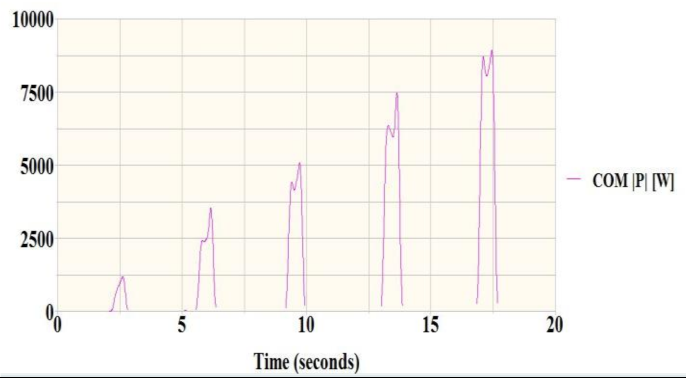
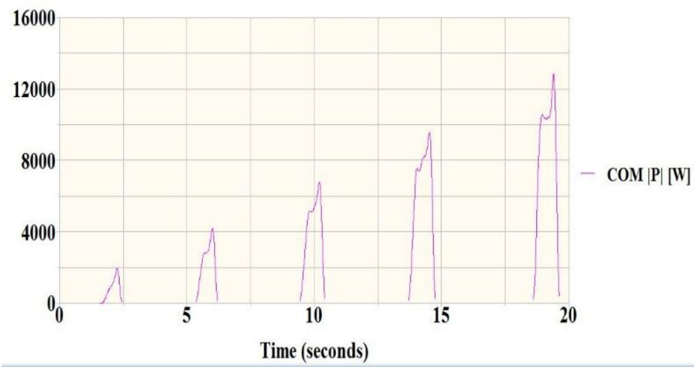
<tr><td>
</td><td>
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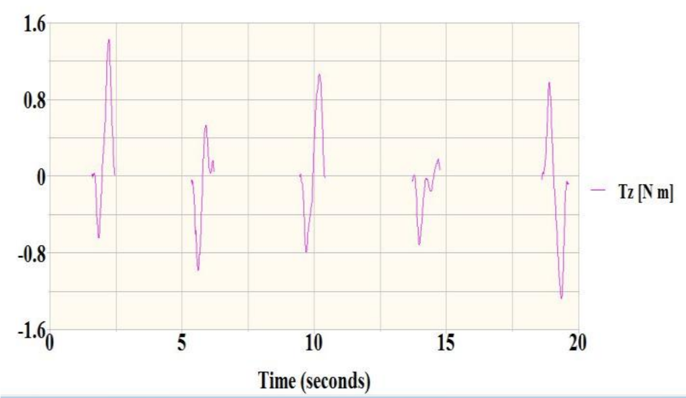
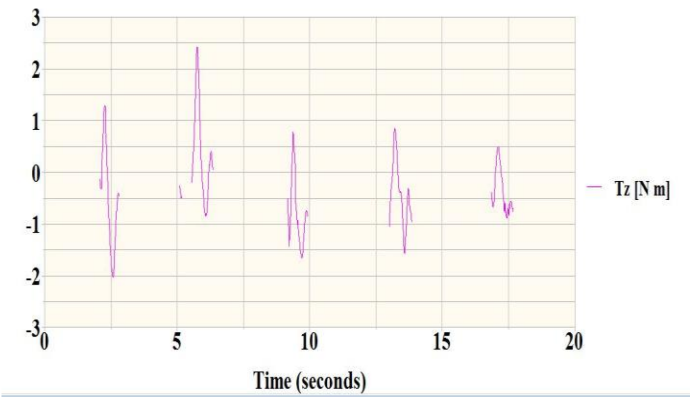
<tr><td>
</td><td>
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4.13 Volunteer 3

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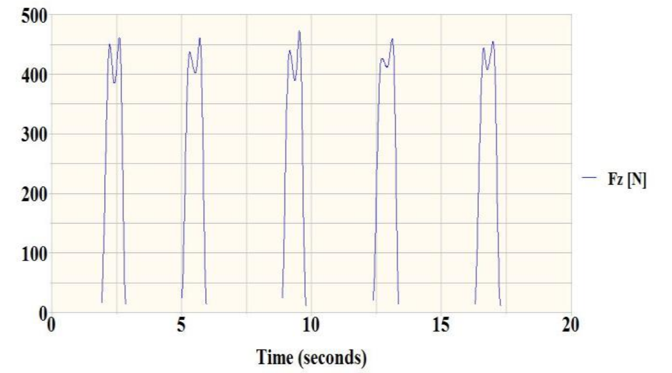

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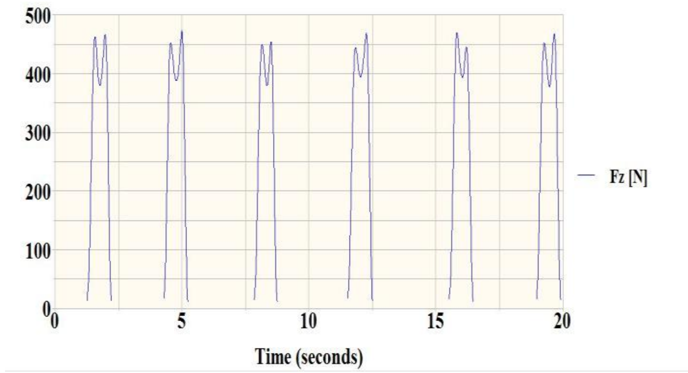

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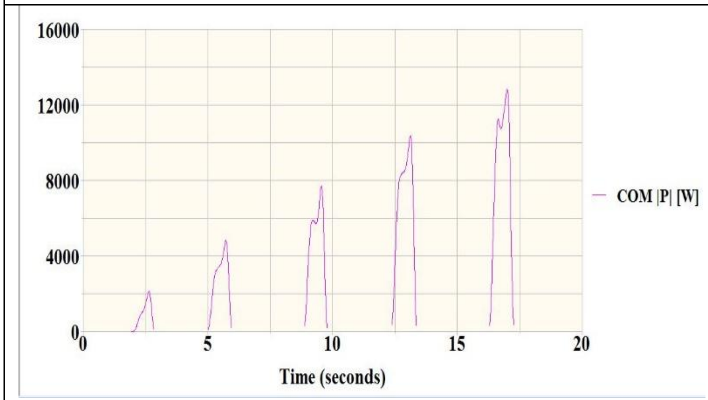

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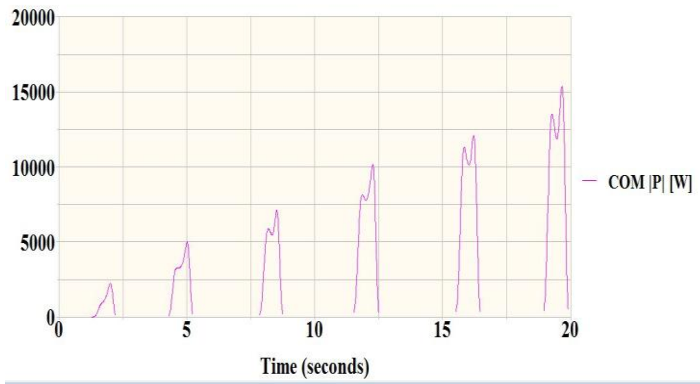

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<tr><td>Fig 4.14 Power Expenditure for Volunteer 3</td><td>Fig 4.17 Power Expenditure for Volunteer 3</td></tr>
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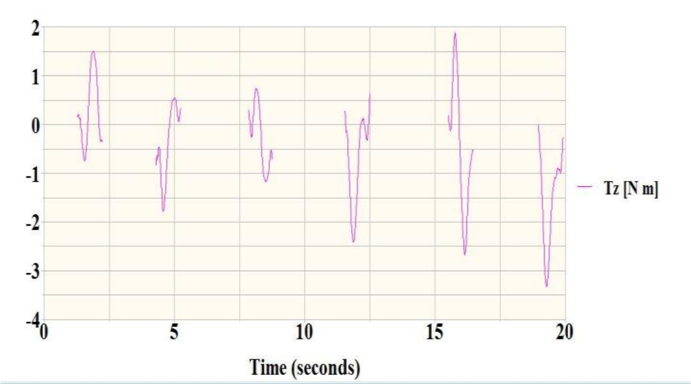

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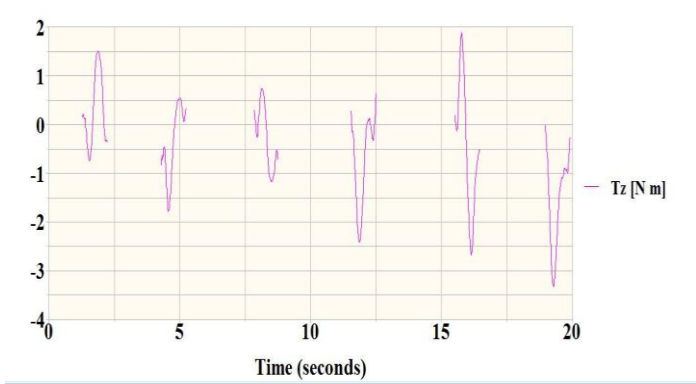

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<tr><td>Fig 4.15 Torque Profile for Volunteer 3</td><td>Fig 4.18 the Torque Profile for Volunteer 3</td></tr>
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4.14 Volunteer 4

Barefoot	High Heels
Ground Reaction Force	
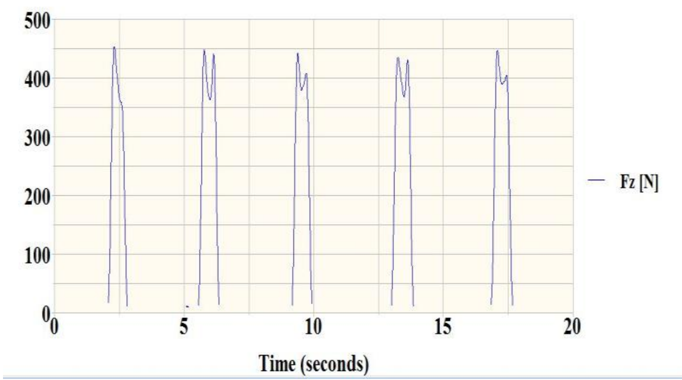	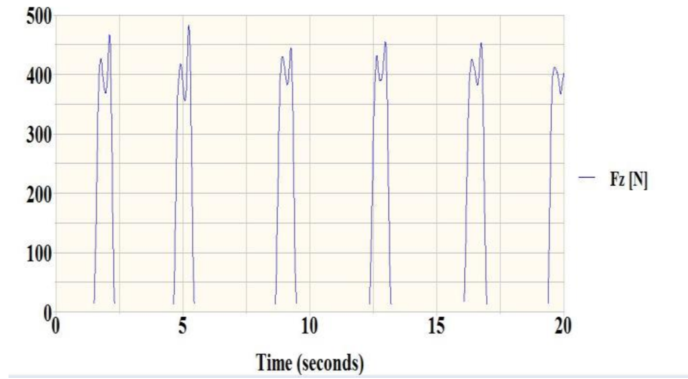
Fig 4.19 Ground Reaction Forces for Volunteer 4	**Fig 4.22 Ground Reaction Forces for Volunteer 4**
Power Expenditure	
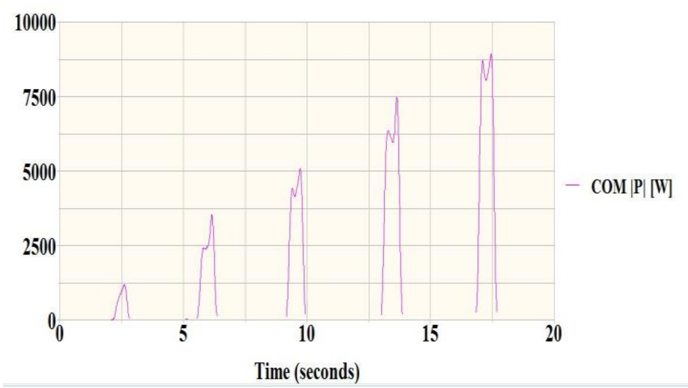	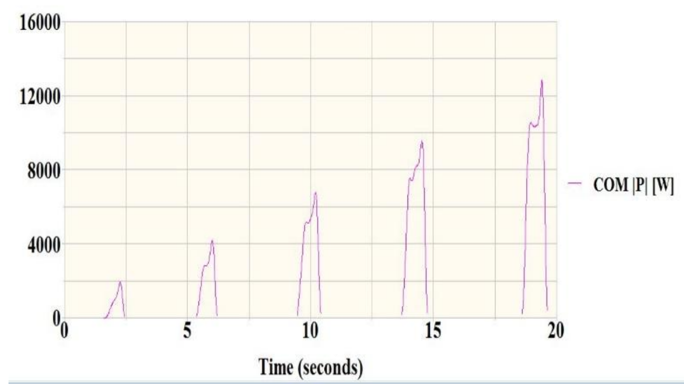
Fig 4.20 Power Expenditure for Volunteer 4	**Fig 4.23 Power Expenditure for Volunteer 4**
Torque	
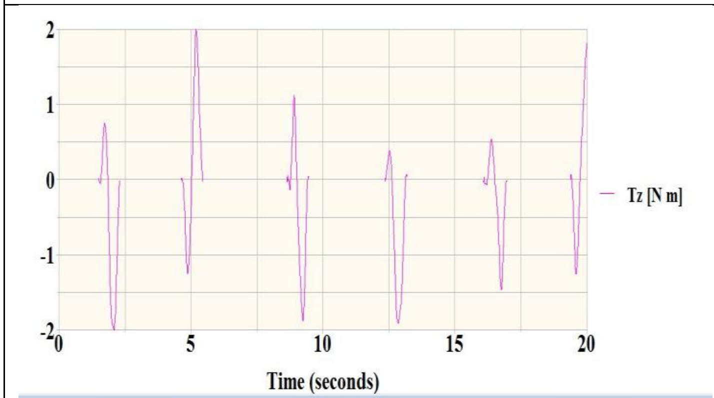	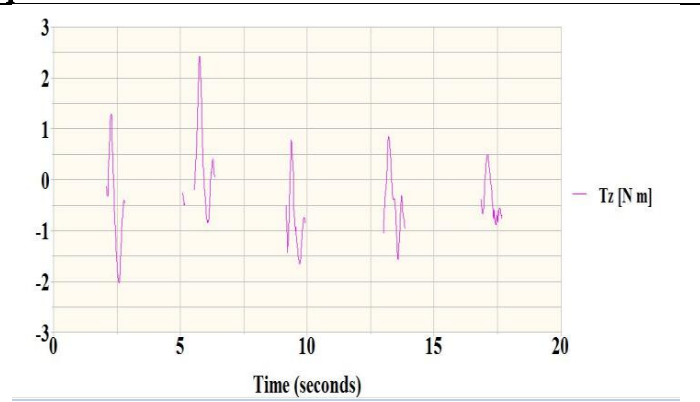
Fig 4.21 Torque Profile for Volunteer 4	**Fig 4.24 Torque Profile for Volunteer 4**

4.15 Volunteer 5

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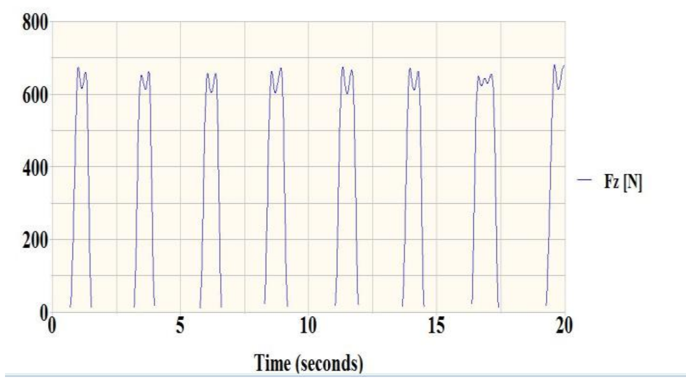
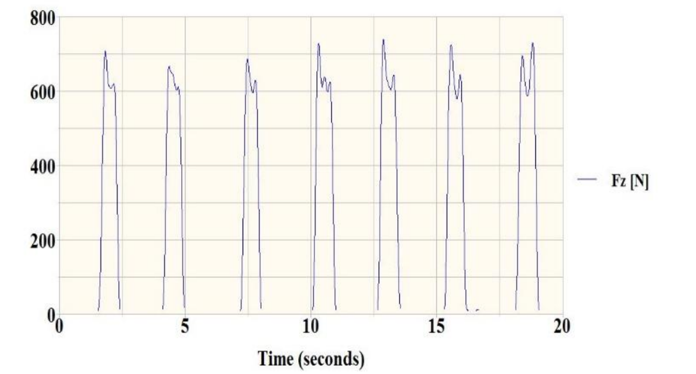
<tr><td>
</td><td>
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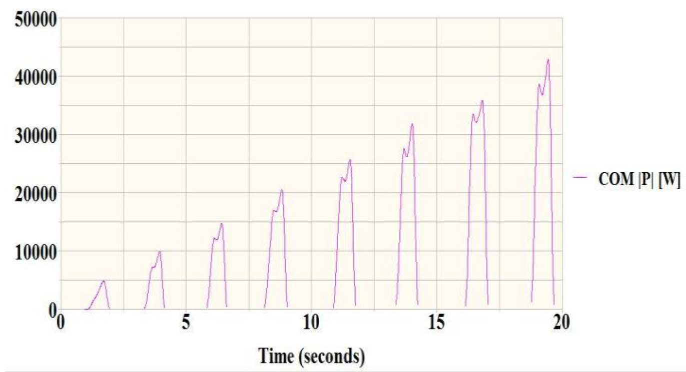
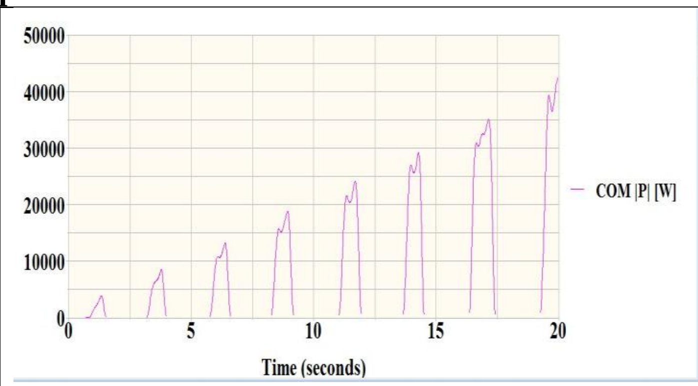
<tr><td>
</td><td>
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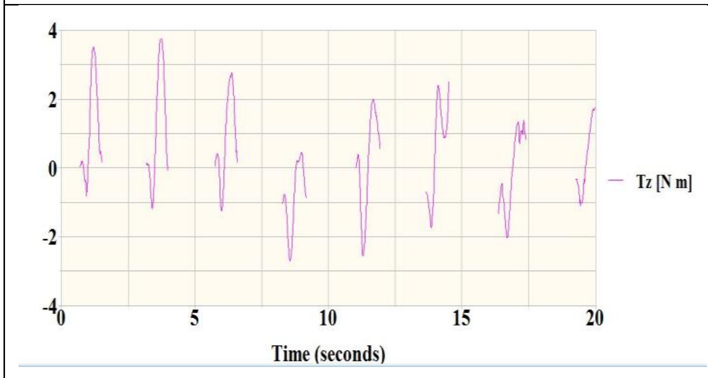
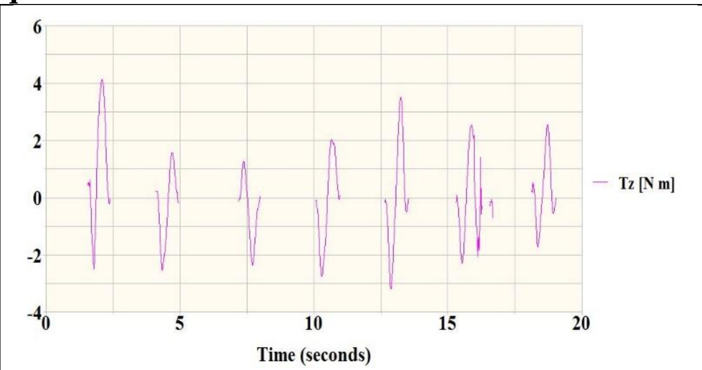
<tr><td>
</td><td>
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4.16 Volunteer 6

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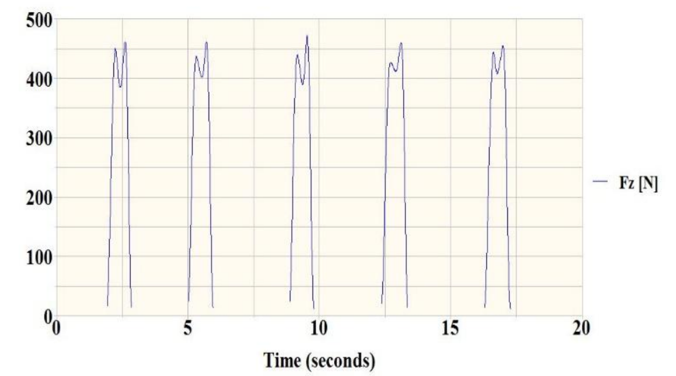
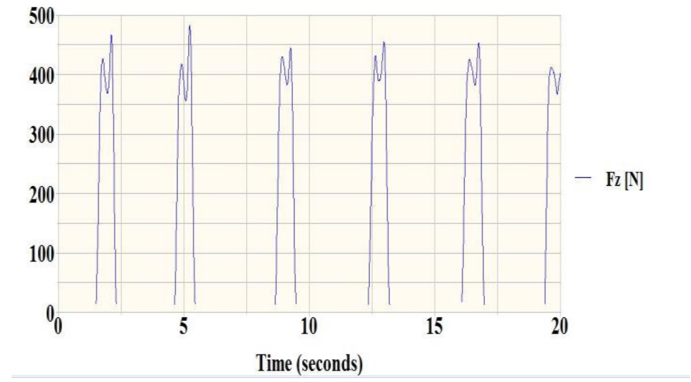
<tr><td>
</td><td>
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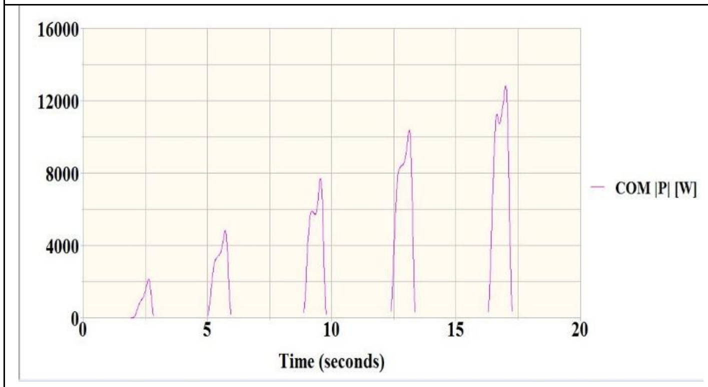
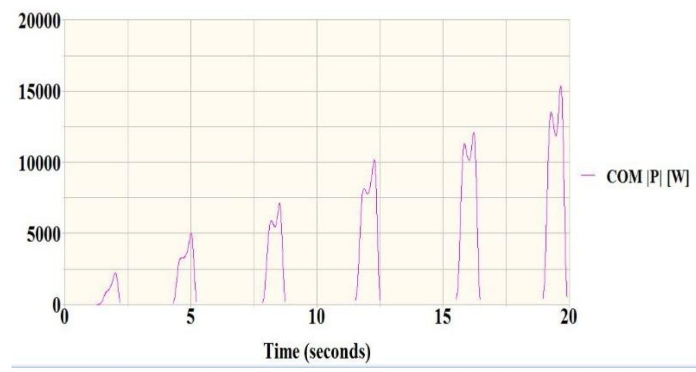
<tr><td>
</td><td>
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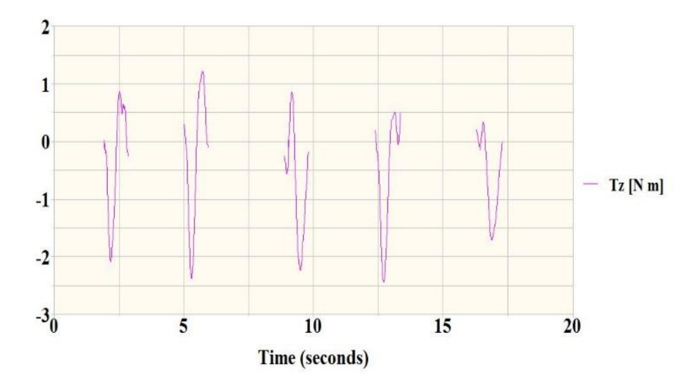
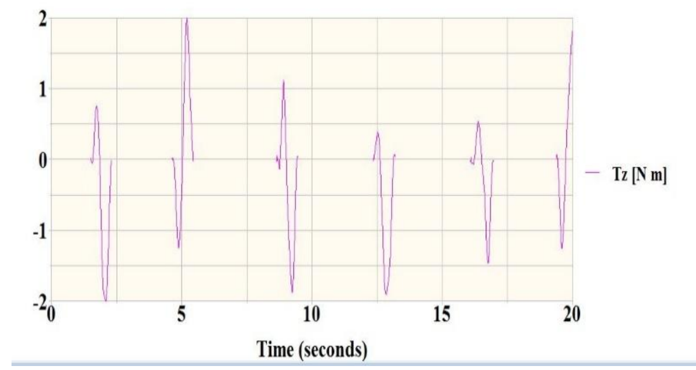
<tr><td>
</td><td>
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4.17 Volunteer 7

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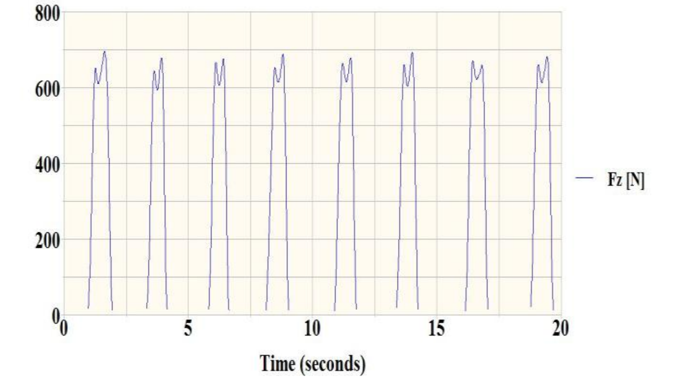
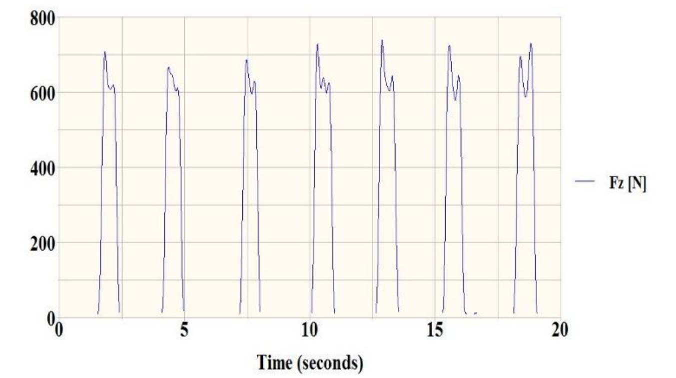
<tr><td></td><td></td></tr>
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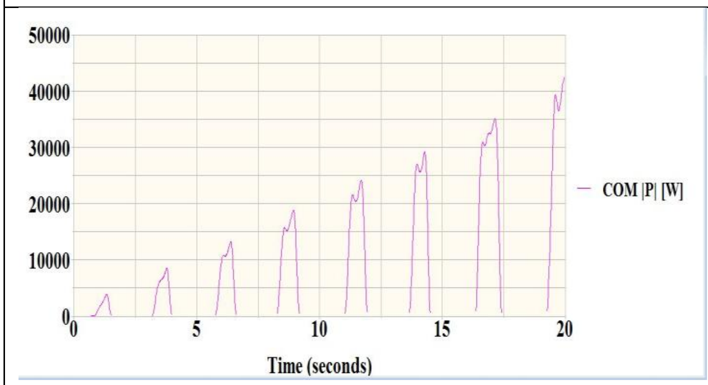
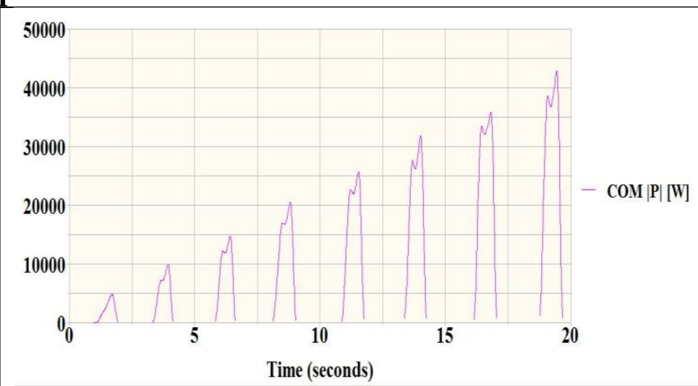
<tr><td></td><td></td></tr>
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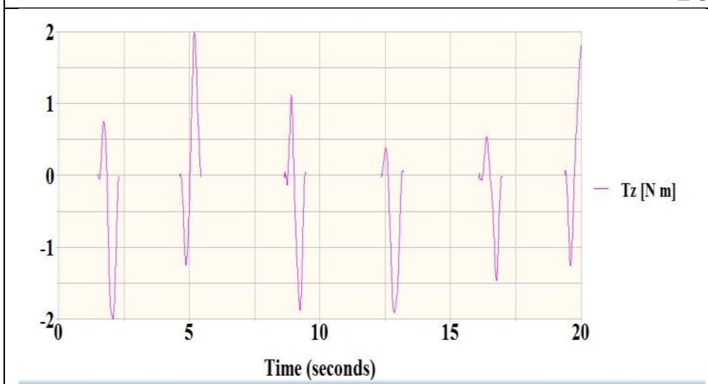
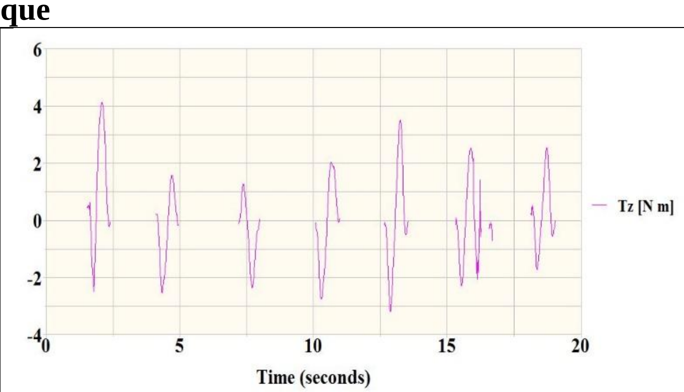
<tr><td></td><td></td></tr>
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4.18 Volunteer 8

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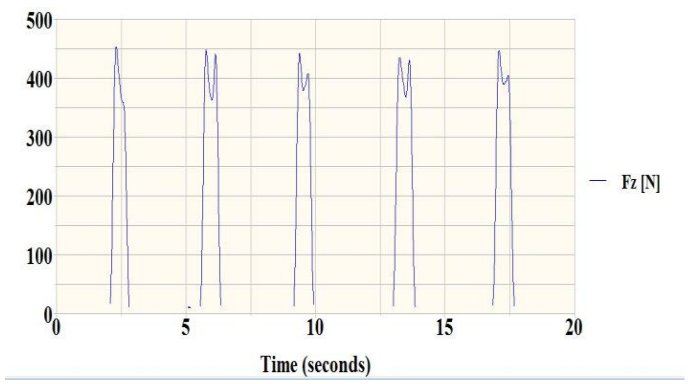
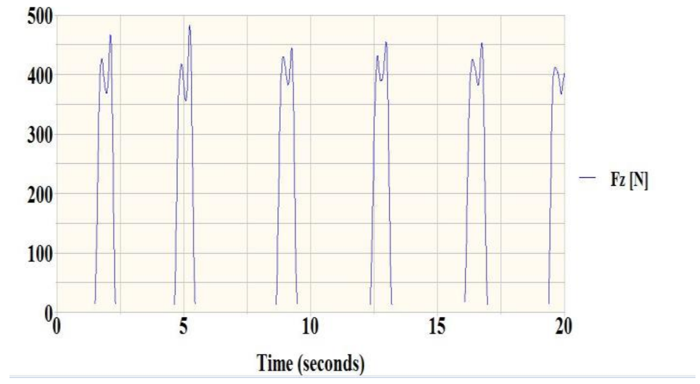
<tr><td>
</td><td>
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<tr><td>Fig 4.43 Ground Reaction Forces for Volunteer 8</td><td>Fig 4.46 Ground Reaction Forces for Volunteer 8</td></tr>
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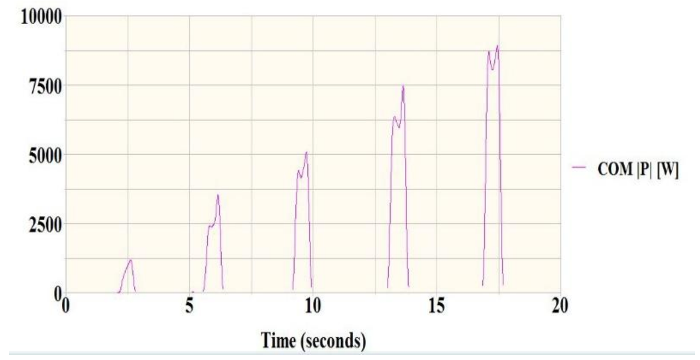
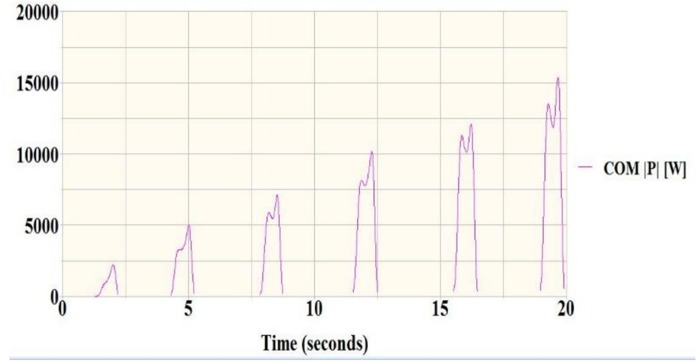
<tr><td>
</td><td>
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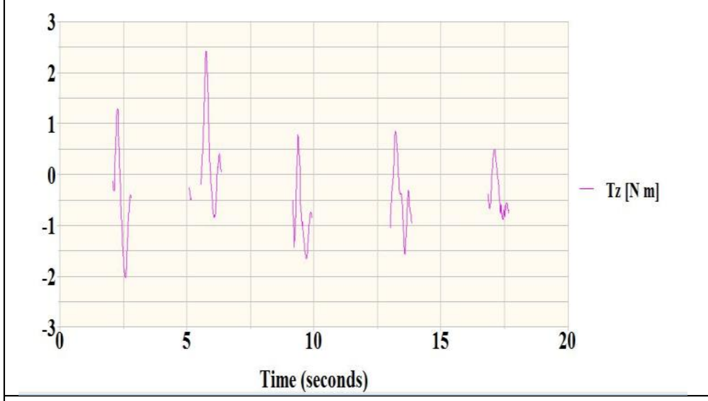
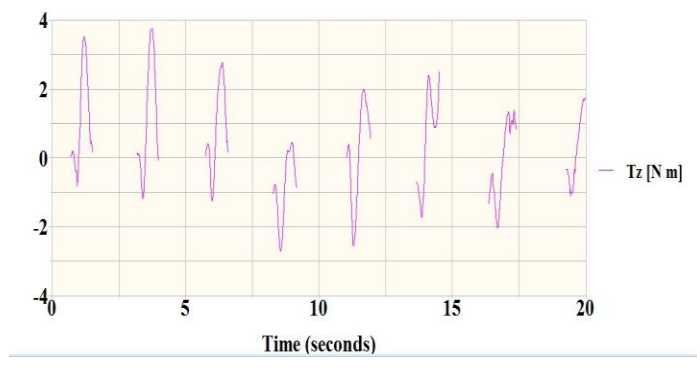
<tr><td>
</td><td>
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<tr><td>Fig 4.45 Torque Profile for Volunteer 8</td><td>Fig 4.48 Torque Profile for Volunteer 8</td></tr>
</table>

4.2 STATISTICAL ANALYSIS

Ground Reaction Forces

Volunteer 1(heel strike and toe lift)

Table 4.21 Volunteer 1(heel strike and toe lift) for barefoot gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.25	649.42	658.62	8.991332	-9.2
3.62	645.1	658.62	8.991332	-13.52
6.11	667.37	658.62	8.991332	8.75
8.47	653.05	658.62	8.991332	-5.57
11.2	664.93	658.62	8.991332	6.31
13.69	658.72	658.62	8.991332	0.1
16.44	670.88	658.62	8.991332	12.26
19.09	659.49	658.62	8.991332	0.87

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
1.62	694.97	681.2063	11.84438	13.76375
3.91	677.83	681.2063	11.84438	-3.3763
6.4	675.85	681.2063	11.84438	-5.3563
8.79	687.17	681.2063	11.84438	5.9637
11.51	675.48	681.2063	11.84438	-5.7263
14	695.45	681.2063	11.84438	14.2437
16.8	659.39	681.2063	11.84438	-21.8163
19.43	683.51	681.2063	11.84438	2.3037

Table 4.22 Volunteer 1(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.83	706.41	703.6857	25.57165	2.7243
4.34	662.36	703.6857	25.57165	-41.3257
7.48	685.1	703.6857	25.57165	-18.5857
10.31	726.39	703.6857	25.57165	22.7043
12.86	731.52	703.6857	25.57165	27.8343
15.57	723.6	703.6857	25.57165	19.9143
18.42	690.42	703.6857	25.57165	-13.2657

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.15	619.63	641.9714	38.34946	-22.3414
4.17	611.34	641.9714	38.34946	-30.6314
7.77	627.07	641.9714	38.34946	-14.9014
10.76	625.55	641.9714	38.34946	-16.4214
13.27	640.04	641.9714	38.34946	-1.9314
15.93	645.25	641.9714	38.34946	3.2786
18.83	724.92	641.9714	38.34946	82.9486

Volunteer 2(heel strike and toe lift)

Table 4.23 Volunteer 2(heel strike and toe lift) for barefoot gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
2.24	449.77	439.22	8.752999	10.55
5.37	437.25	439.22	8.752999	-1.97
9.17	439.43	439.22	8.752999	0.21
12.7	426.09	439.22	8.752999	-13.13
17.26	443.56	439.22	8.752999	4.34

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.61	461.24	460.778	6.704806	0.462
5.7	460.72	460.778	6.704806	-0.058
9.52	471.53	460.778	6.704806	10.752
13.53	456.14	460.778	6.704806	-4.638
16.99	454.26	460.778	6.704806	-6.518

Table 4.24 Volunteer 2(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.57	462.52	453.8417	10.57044	8.678333
4.56	451.8	453.8417	10.57044	-2.0417
8.13	443.63	453.8417	10.57044	-10.2117
11.85	442.75	453.8417	10.57044	-11.0917
15.83	469.67	453.8417	10.57044	15.8283
19.26	452.68	453.8417	10.57044	-1.1617

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
1.98	466.27	462.31	10.6785	3.96
5	472.97	462.31	10.6785	10.66
8.5	453.51	462.31	10.6785	-8.8
12.26	468.86	462.31	10.6785	6.55
16.2	445.08	462.31	10.6785	-17.23
19.65	467.17	462.31	10.6785	4.86

Volunteer 3(heel strike and toe lift)

Table 4.25 Volunteer 3(heel strike and toe lift) for barefoot gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.88	421.12	429.808	5.586	-8.688
5.65	423.41	429.808	5.586	-6.398
9.7	435.22	429.808	5.586	5.412
14.02	432.15	429.808	5.586	2.342
18.92	437.14	429.808	5.586	7.332

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.63	379.82	411.552	22.93095	-31.732
6.13	439.94	411.552	22.93095	28.388
9.7	407.27	411.552	22.93095	-4.282
13.64	426.39	411.552	22.93095	14.838
17.43	404.34	411.552	22.93095	-7.212

Table 4.26 Volunteer 3(heel strike and toe lift) for wedged heels gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
2.09	453.03	445.192	6.734031	7.838
5.77	447.86	445.192	6.734031	2.668
9.39	442.28	445.192	6.734031	-2.912
13.25	435.25	445.192	6.734031	-9.942
17.09	447.54	445.192	6.734031	2.348

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.24	458.85	453.84	7.158014	5.01
6.01	452.41	453.84	7.158014	-1.43
10.21	451.01	453.84	7.158014	-2.83
14.53	446.78	453.84	7.158014	-7.06
19.41	460.15	453.84	7.158014	6.31

Volunteer 4(heel strike and toe lift)

Table 4.27 Volunteer 4(heel strike and toe lift) for barefoot gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
2.66	436.87	444.428	11.46694	-7.558
5.72	459.26	444.428	11.46694	14.832
9.12	444.98	444.428	11.46694	0.552
13.55	432.93	444.428	11.46694	-11.498
18.61	448.1	444.428	11.46694	3.672

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.98	469.66	455.528	9.921145	14.132
5.85	451.38	455.528	9.921145	-4.148
10.16	449.22	455.528	9.921145	-6.308
14.32	445.62	455.528	9.921145	-9.908
19.31	461.76	455.528	9.921145	6.232

Table 4.28 Volunteer 4(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.62	464.59	455.2367	10.87889	9.353333
4.43	452.61	455.2367	10.87889	-2.6267
8.1	441.97	455.2367	10.87889	-13.2667
11.88	446.47	455.2367	10.87889	-8.7667
15.79	470.87	455.2367	10.87889	15.6333
19.16	454.91	455.2367	10.87889	-0.3267

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.05	467.54	464.3964	10.0714	3.143636
4.96	473.89	464.3964	10.0714	9.4936
8.57	459.61	464.3964	10.0714	-4.7864
12.38	471.86	464.3964	10.0714	7.4636
16.31	446.82	464.3964	10.0714	-17.5764
19.73	468.92	464.3964	10.0714	4.5236

Volunteer 5(heel strike and toe lift)

Table 4.29 Volunteer 5(heel strike and toe lift) for barefoot gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.58	650.73	658.25	9.051836	-7.52
3.59	643.91	658.25	9.051836	-14.34
6.18	665.48	658.25	9.051836	7.23
8.51	653.05	658.25	9.051836	-5.2
11.47	665.83	658.25	9.051836	7.58
13.53	655.72	658.25	9.051836	-2.53
16.39	671.07	658.25	9.051836	12.82
19.32	660.21	658.25	9.051836	1.96

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
1.83	692.17	672.1075	14.50842	20.0625
4.16	658.15	672.1075	14.50842	-13.9575
6.68	670.43	672.1075	14.50842	-1.6775
8.89	678.63	672.1075	14.50842	6.5225
12.06	663.28	672.1075	14.50842	-8.8275
13.86	690.29	672.1075	14.50842	18.1825
16.93	651.56	672.1075	14.50842	-20.5475
19.97	672.35	672.1075	14.50842	0.2425

Table 4.30 Volunteer 5(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.73	702.63	703.6857	24.5478	-1.0557
4.45	667.38	703.6857	24.5478	-36.3057
7.69	684.92	703.6857	24.5478	-18.7657
10.26	727.45	703.6857	24.5478	23.7643
12.72	731.96	703.6857	24.5478	28.2743
15.61	725.87	703.6857	24.5478	22.1843
18.61	693.81	703.6857	24.5478	-9.8757

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.07	620.59	647.38	38.83195	-26.79
4.83	619.63	647.38	38.83195	-27.75
7.94	630.92	647.38	38.83195	-16.46
10.93	730.46	647.38	38.83195	83.08
13.29	639.74	647.38	38.83195	-7.64
15.99	642.94	647.38	38.83195	-4.44
18.92	628.41	647.38	38.83195	-18.97

Volunteer 6(heel strike and toe lift)

Table 4.31 Volunteer 6(heel strike and toe lift) for barefoot gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
2.42	462.74	448.83	10.95174	13.91
5.69	445.82	448.83	10.95174	-3.01
9.38	439.6	448.83	10.95174	-9.23
13.48	438.69	448.83	10.95174	-10.14
18.48	457.3	448.83	10.95174	8.47

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
3.16	465.48	456.658	7.229178	8.822
6.23	457.69	456.658	7.229178	1.032
10.04	446.28	456.658	7.229178	-10.378
14.27	453.58	456.658	7.229178	-3.078
19.22	460.26	456.658	7.229178	3.602

Table 4.32 Volunteer 6(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.54	469.52	456.9817	10.43677	12.53833
4.19	457.93	456.9817	10.43677	0.9483
7.95	449.39	456.9817	10.43677	-7.5917
11.67	453.65	456.9817	10.43677	-3.3317
15.64	468.24	456.9817	10.43677	11.2583
18.96	443.16	456.9817	10.43677	-13.8217

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.21	464.39	464.0373	16.27205	0.352727
4.83	478.65	464.0373	16.27205	14.6127
8.69	452.16	464.0373	16.27205	-11.8773
12.5	479.43	464.0373	16.27205	15.3927
16.44	439.61	464.0373	16.27205	-24.4273
19.68	475.93	464.0373	16.27205	11.8927

Volunteer 7(heel strike and toe lift)

Table 4.33 Volunteer 7(heel strike and toe lift) for flat shoes gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.36	645.1	658.4525	10.47564	-13.3525
3.46	667.37	658.4525	10.47564	8.9175
5.87	642.87	658.4525	10.47564	-15.5825
8.29	670.88	658.4525	10.47564	12.4275
10.9	664.93	658.4525	10.47564	6.4775
13.07	653.05	658.4525	10.47564	-5.4025
16.14	658.49	658.4525	10.47564	0.0375
18.74	664.93	658.4525	10.47564	6.4775

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
1.94	687.62	679.1588	13.79685	8.46125
4.05	671.29	679.1588	13.79685	-7.8688
6.67	684.38	679.1588	13.79685	5.2212
8.84	679.81	679.1588	13.79685	0.6512
11.62	686.73	679.1588	13.79685	7.5712
13.79	697.62	679.1588	13.79685	18.4612
16.93	651.84	679.1588	13.79685	-27.3188
19.6	673.98	679.1588	13.79685	-5.1788

Table 4.34 Volunteer 7(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.76	702.65	695.7634	22.26812	6.8866
4.25	674.83	695.7634	22.26812	-20.9334
6.73	682.8	695.7634	22.26812	-12.9634
9.37	728.94	695.7634	22.26812	33.1766
11.63	696.73	695.7634	22.26812	0.9666
14.29	734.8	695.7634	22.26812	39.0366
18.7	695.72	695.7634	22.26812	-0.0434

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.25	625.87	646.4429	29.16788	-20.5729
4.29	618.76	646.4429	29.16788	-27.6829
7.38	648.67	646.4429	29.16788	2.2271
10.53	627.48	646.4429	29.16788	-18.9629
13.63	645.87	646.4429	29.16788	-0.5729
15.7	652.76	646.4429	29.16788	6.3171
19.36	705.69	646.4429	29.16788	59.2471

Volunteer 8(heel strike and toe lift)

Table 4.35 Volunteer 8(heel strike and toe lift) for wedged heels gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.36	545.1	559.7025	11.86365	-14.6025
3.46	567.37	559.7025	11.86365	7.6675
5.87	542.87	559.7025	11.86365	-16.8325
8.29	570.88	559.7025	11.86365	11.1775
10.9	574.93	559.7025	11.86365	15.2275
13.07	553.05	559.7025	11.86365	-6.6525
16.14	558.49	559.7025	11.86365	-1.2125
18.74	564.93	559.7025	11.86365	5.2275

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
1.94	577.62	571.6588	14.47718	5.96125
4.05	571.29	571.6588	14.47718	-0.3688
6.67	584.38	571.6588	14.47718	12.7212
8.84	579.81	571.6588	14.47718	8.1512
11.62	586.73	571.6588	14.47718	15.0712
13.79	547.62	571.6588	14.47718	-24.0388
16.93	551.84	571.6588	14.47718	-19.8188
19.6	573.98	571.6588	14.47718	2.3212

Table 4.36 Volunteer 8(heel strike and toe lift) for high heeled gait

time	Fz(heel strike)	Average	STD.DEV	STD.ERR
1.76	602.65	602.3629	22.26466	0.287143
4.25	574.83	602.3629	22.26466	-27.5329
6.73	582.8	602.3629	22.26466	-19.5629
9.37	628.94	602.3629	22.26466	26.5771
11.63	596.73	602.3629	22.26466	-5.6329
14.29	634.8	602.3629	22.26466	32.4371
18.7	595.79	602.3629	22.26466	-6.5729

time	Fz (toe lift)	Average	STD.DEV	STD.ERR
2.25	525.87	532.1571	17.44798	-6.28714
4.29	518.76	532.1571	17.44798	-13.3971
7.38	548.67	532.1571	17.44798	16.5129
10.53	527.48	532.1571	17.44798	-4.6771
13.63	545.87	532.1571	17.44798	13.7129
15.7	552.76	532.1571	17.44798	20.6029
19.36	505.69	532.1571	17.44798	-26.4671

Power

Mass	Cumulative power for high heeled gait	Cumulative power for without heels
43	8915	7536
46	10031	7442
48	12843	10837
54	15385	12081
55	24419	20613
59	30117	25735
66	42753	34931

Table 4.37 Power Expenditure for high heeled and barefoot w.r.t mass

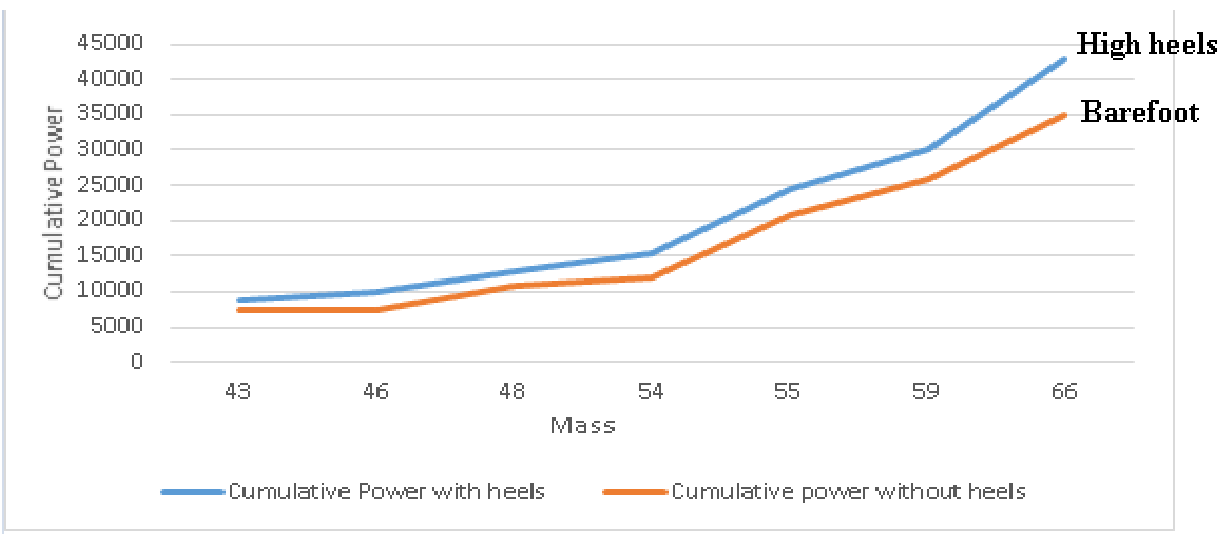

Fig 4.52 Cumulative Power expenditure vs mass

4.3 Discussion

1. Considering Fig 4.1 and 4.4, it can be seen that there is a significant rise in the Ground Reaction Forces (GRF) when it comes to the part where the volunteer is wearing high heeled shoes in comparison with the part where the volunteer is walking barefoot. The reaction force on the ankle is higher in the case of high heeled shoes than in the case of barefoot walking. The excessive force acting on the ankle has deteriorating effect on the joint. As shown by previous studies the GRF plays an important role in the well being of the ankle joint. It has also been found that the GRFs' magnitude increase with increase in speed. Thus it is the evidence that increase in the heel height increases the GRFs and thus speeds up the deterioration of the ankle joint.

2. Considering Fig 4.2 and 4.5, it is observed that the power expenditure in case of high heeled walking is much higher than the power expenditure in the barefoot walk. Thus walking in high heeled shoes is much more expensive than the walking barefoot, considering metabolic energy expenditures. The cost to the body increases significantly in high heeled gait as compared to barefoot gait. The striking significance is that it can be correlated to the fact that women find it difficult to keep on wearing high heeled shoes for continuously for longer period of time (this gives rise to chronic pain and distortion of metatarso-phalangeal joint). This is also due to excessive GRF that acts on the ankle, the force applied is also concentrated around the ankle region, and this creates a lot of pressure and induces pain in the ankle joint.

3. Considering Fig 4.3 and 4.6, it can be clearly seen that the torque acting on the ankle joint in high heeled gait is much higher than the torque acting on the ankle joint in normal barefooted gait. But the main concern is not only the unidirectional torque but the reverse torque. During heel strike the frictional force acts in the opposite direction of the motion and creates an anticlockwise torque. During toe lift, the frictional force acts in the direction of the motion thus producing a torque in the clockwise direction. Considering the ankle joint as a screw which is rotated in both the direction with high speed, then the rate of wearing becomes more with respect to the rate of wearing that would occur when the screw rotates at a slower pace. Here it was seen the torque as well as the reverse torque is greater in case of the high heeled gait thus increasing the rate of wear of the subtalar joint.

Magnitude of the torque is the responsible factor in rapid wearing of the subtalar joint. Similar trend was observed for Volunteers 2, 4, 5 and 6.

4. Considering Fig 4.13 and Fig 4.16, we see that there is an increase in the GRF from the barefoot gait in the wedged heel gait but the increase is very small, the reason being the heel height. The heel height was smaller as compared to the high heel used by volunteer 1 and 2. In addition to that the wedged heel distributes the GRF across the foot preventing the force to concentrate around a small surface as in the case of the pointed heels. This establishes the fact that the GRF acting on the ankle is proportional to the heel height. As the heel height increases the GRF acting on the ankle increases.

5. Considering Fig 4.14 and Fig 4.17, Fig 4.15 and Fig 4.18, same observation was made in the case of the high heeled shoes and bare foot, but the difference is that the change magnitude of power and torque is very small as compared to the high heeled volunteer. This shows that wedged low heels have less deteriorating effect on the ankle joint. The power expenditure is just a little bit higher in the case of wedged heels as compared to the barefoot gait. Also the maximum torque applied on the ankle joint is within a tolerable range where it is almost equal to that of the barefoot gait.

6. Flat shoes vs High heels: Taking into account Fig 4.43 and Fig 4.46, Fig 4.44 and Fig 4.47, Fig 4.45 and Fig 4.48, the high heeled gait of Volunteer 7 shows more or less the same results as in Fig 4.1 to 4.3, the flat-shoe-gait of Volunteer 7 shows that the GRF experienced in this case is lesser than the GRF experienced in the case of high heels. In addition, the power consumption in case of flat shoes is much lesser than that of the high heeled shoes, thus making it more comfortable to walk in. The flat sole of the shoe distributes the GRF uniformly over the surface thus creating no discomfort and pain. The torque acting on the ankle joint is very less in the case of the flat shoes. Thus the deterioration rate is also very low when flat shoes are used.

7. Wedged Heels vs High Heels: Considering Fig 4.43 and Fig 4.46, Fig 4.44 and Fig 4.46, Fig 4.45 and Fig 4.48. The high heeled gait of Volunteer 8 shows the same results as in Fig 4.1 to 4.3, The wedged heels gait of Volunteer 8 shows that the GRF experienced in this case is lesser than the GRF experienced in the case of high heels, plus the power consumption in case of wedged heels is

considerably lesser than that of the high heeled shoes, thus making it more comfortable to walk in. The wedge heels of the shoe distributes the GRF uniformly over the surface thus creating no discomfort and pain. The torque acting on the ankle joint is less in the case of the wedged heels. Thus the deterioration rate is also very low when wedged heels are used. [The wedged heels also increase the style quotient with minimal cost to the body.]

8. Prolonged usage of high-heels changes the body posture. The curvature of the spine tends to increase around the thoracic region. The angle between the pelvic and spine along the sagittal plane increases. There is noticeable tightening of the calf muscles. When a person is standing straight up without using heels, the body creates a right angle with the floor, which constitutes a normal stance. Assuming the body to be a rigid column, wearing a pair of heels would push the entire body to slant or tilt forward, and the angle made with the floor would go down or, in other words, become acute. As height of the heel increases, the angle decreases and gives the body more slanting configuration. However, in reality the body is not at all a rigid column, so in order to wear high-heels and maintain a normal stance, a series of joint adjustments, especially in the spine, is required. The body's response to this change in angle makes the graceful, curved, high-heeled posture.

9. The above done statistical analysis, in Table 4.21 to 4.36 shows, that the standard deviation in case of high heeled gait is more than the standard deviation obtained in the barefoot or normal gait. This can be attributed to the fact that during high heeled gait the volunteer or the person wearing high heels makes a slight adjustment in the body configuration with every step. Thus force acting through the toe and the heels are different every time thus invoking a different GRF. It also shows that the average GRF acting on the body is more in case of high heeled gait than in the case of normal gait.

10. The power statistics, in Table 4.37, show that the cumulative power expenditure is always higher in high heeled gait than in normal gait. The mass versus cumulative power in Fig 4.52 shows that for shoes of same heel height the cumulative power expenditure increases non linearly (exponentially) with increase in the mass of the volunteer or person wearing it, As the mass increases the cumulative power difference between normal gait and high heeled gait increases thus showing that a person with more mass has to expend more power in walking in high heeled shoes than a comparatively thinner person.

CONCLUSION:

In this era where style and looks are evolving, every female is pressured to use high heeled shoes to look elegant, suave and graceful. But undermining the ill effects of high heeled shoes will lead to ankle related problems, ache and other orthopedic pathologies. In the above array of discussion it has been seen that the parameters considered have enough negative impacts on the ankle joint and one can only imagine the effects of using them for longer durations of time. The best alternative would be to use wedge-type heels which provide the necessary uplift and also minimize the effect of the external forces to a great extent making it more comfortable while not compromising with the style quotient. Wedge heels also distribute the forces across the whole foot leaving no high pressure points.

REMEDIES:

1. Choosing sensible heels.

   Selecting shoes with low heels - an inch and a half or less - and a wide heel base; a slightly thicker heel will spread the load more evenly. Narrow, stiletto-type heels provide little support and three inch or higher heels may shorten the Achilles tendon.

2. Wearing soft insoles to reduce the impact on the knees.

3. Making sure the shoes are of the right size so that foot doesn't slide forward, putting even more pressure on the toes. Picking a shoe with a wide enough toe box to allow wiggling of toes.

4. Wearing heels on days that require limited walking or standing.

5. Stretch:

   Taking time every day to stretch the calf muscles and feet. Recommended posture is standing on the edge of a step with shoes off. With the weight on the feet and the heels extending off the edge, dropping the heels down to stretch.

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